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Tests of Reinforced Concrete Beams Comparison of Methods of Loading

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TESTS OF REINFORCED CONCRETE BEAMS

COMPARISON OF METHODS OF LOADING

BY

VIRGIL R. FLEMING

THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

COLLEGE OF ENGINEERING

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May 26, 1905

This is to certify that the following thesis prepared under the direction of Professor A. N. Talbot, Head of the Department of Municipal and Sanitary Engineering, by

VIRGIL R FLEMING

entitled TESTS OF REINFORCED CONCRETE BEAMS
VARIOUS METHODS OF LOADING

is accepted by me as fulfilling this part of the requirements for the Degree of Bachelor of Science in Civil Engineering

Ira O Baker

Head of Department of Civil Engineering

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TEST OF REINFORCED CONCRETE BEAMS.

VARIOUS METHODS OF LOADING.

The experiments described in the following pages comprise a part of extensive tests carried on in the United States, under the direction of a Joint Committee appointed by four of the leading American engineering and technical societies; and more especially a subdivision of the work along this line, undertaken at the University of Illinois.

The investigation reported in this thesis is the comparison of the general behavior of reinforced concrete beams under three different methods of loading; first, the load applied at the one-third points; second, the load applied at the center of the span, which will be referred to as a concentrated load; third, the load applied at eight points, which will be referred to as a uniform load.

Various tests made in the country in the last four years apparently indicate that a beam loaded at the center will develop a greater resisting moment than a beam loaded at the one-third points. Also tests have been made by Mr. Kahn with a so-called uniform load/by piling pig iron on top of the beam. The results have indicated a stress beyond the ultimate strength of the steel, if there is assumed to be no arch action in the loading. This test will be carried out under a different method of loading, such that there can be no chance of arch action of loading.

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The following divisions will be made:—I. Description of Materials, II. Description of Test Pieces, III. Details of Tests, IV. Observed Data, V. Discussion.

I. DESCRIPTION OF MATERIALS.

The concrete used for the beams in these tests was made of the proportions one part cement, three parts sand and six parts broken lime stone, measured by loose volume. The steel consisted of 1/2 in. round steel rods.

For a full description of materials reference may be made to the thesis presented by Mr. E. T. Renner, June, 1905, entitled, Tests of Reinforced Concrete Beams—Effect of Release of Loads, where all the general descriptions of materials for the entire series of tests are given. All beams were reinforced with 1/2 in. round steel bars of 40000 lb. per sq. in. elastic limit.

II. DESCRIPTION OF TEST PIECES.

The beams were 8 in. x 11 in. by 13 ft. The reinforcement for all beams consisted of four 1/2 in. round rods, placed in a horizontal plane 10 in. below top of beam, making a reinforcement of .96 percent., based upon the area of concrete above the center of the steel. For a general description of the test pieces, reference may be made to thesis by Mr. E. T. Renner as above mentioned.

SUMMARY OF BEAMS.

Beam No.	Date made	Date tested	Method of Loading
5	Feb. 10	April 20	At 1/3 points
11	Feb. 14	April 20	At 1/3 points
21	Feb. 23	April 26	Concentrated
30	Mar. 2	May 3	Concentrated
47	Mar. 10	May 9	Uniform

III. DETAILS OF TESTS.

For a general description of tests reference may be made to thesis submitted by Mr. E. T. Renner as mentioned above.

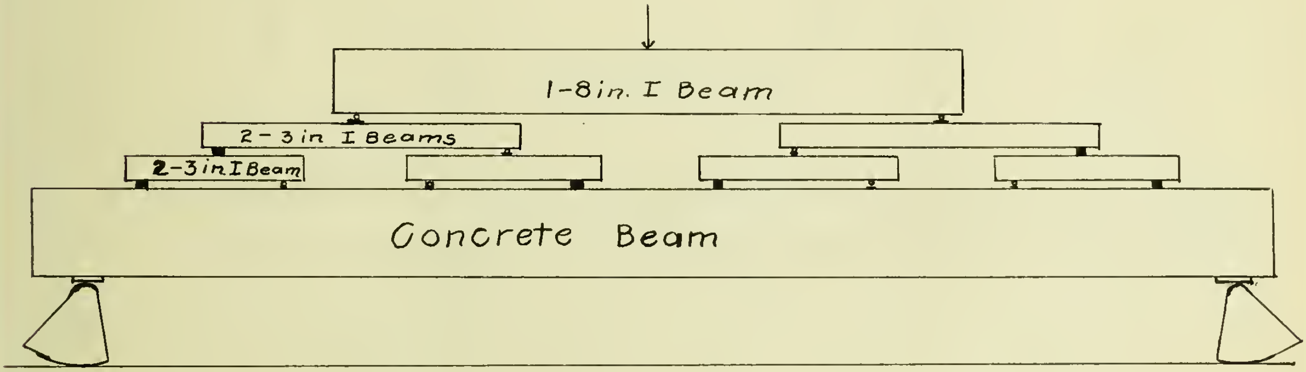
Three different methods of loading were used in these tests.

Beams No. 5 and 11 were loaded at the one-third points of the span. One set of extensometers was used on these beams, the contact points being placed 3 in. outside the load points for Beam No. 5, thus making a span of 54 in.; and 3 in. inside the load points for Beam No. 11, making a span of 42 in.

Beams No. 21 and 30 were loaded at the center of the span. A layer of plaster of paris was placed between the bearing plate and the beam and let set under about 600 lb. load on the beam. To avoid eccentric loading a soft wood block was placed between the pulling head of the machine and the bearing plate. No roller bearing was used at the center. Two sets of extensometers were used on these beams. One set was placed the

same as for Beam No. 11, the other set was placed with the contact points 4 in. on either side of the center for Beam No. 21, making a span of 8 in., and 4-1/2 in. on either side of the center for Beam No. 30, making a span of 9 in. The center of the upper roller was 9-1/4 in. above upper contact point, the distance between contact points 9-1/2 in. the distance from lower contact point to the center of the lower roller was 7-1/4 in.

Only one beam, Beam No. 47, was tested with the load applied at eight points, as shown in sketch below.



Plaster of paris was used for a bearing surface at each load point. Cold rolled steel shafting rollers 3/4 in. in diameter, rolling upon planed steel plates, were used at four load points, flat bars being used at the remaining four load points. Rollers could not have been used at all of the load points on account of the difficulty of keeping the I-beams from

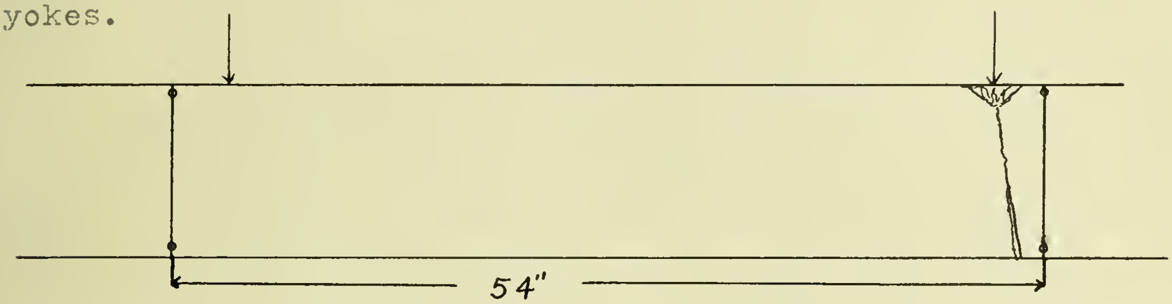
rolling out of position before a load could be applied. Two sets of extensometers were used on this beam. One set was placed at the middle of the beam with a span of 30 in. This set of extensometers had to be adjusted to be used with this loading. The distance from center of roller to upper contact point was 7 in; distance between contact points 9-1/2 in; from lower contact point to center of lower roller 3-3/4 in. The ~~center~~ set was placed near one end of the span, the extensometer span being 36 in., the contact points being placed 6 in. and 42 in. from one support. The adjustment of the extensometer yokes was the same as the yokes for the 8 in. span on Beam No. 21.

IV. OBSERVED DATA.

The original readings of deformations and deflections are given in tables on pages 21 to 28 inclusive of this thesis. The curves for the unit deformations and deflections as computed from the observed data are given in plates on pages 13 to 20 inclusive of this thesis.

BEAM No. 5. This beam was loaded at the one-third points of the span. At 6000 lb. load two small cracks appeared under one load point extending vertically to a heighth of about 3 in. As the load increased this crack opened up and extended upward to within 3 in. of top when the load reached 11,000 lb. which was the maximum. At this point the upper fiber began to crush. No other cracks were noticed at any time during the test. The beam had about 1/4 in. cement mortar on top which probably

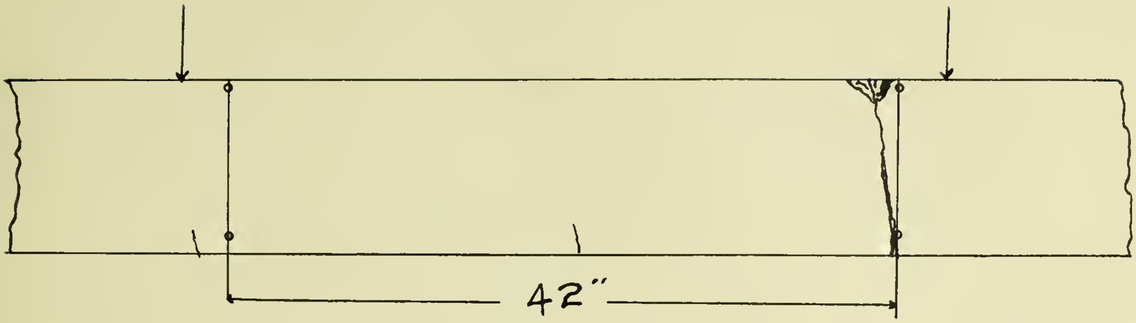
weakened the beam. After the maximum was reached the load ran down to about 9000 lb. and held uniformly until the beam had a deflection of about 3 in., then the load ran down to 7500 lb. and the machine was stopped as the beam was giving way fast under the load. The failure occurred inside the extensometer yokes.



(Above sketch shows manner of failure of beam.)

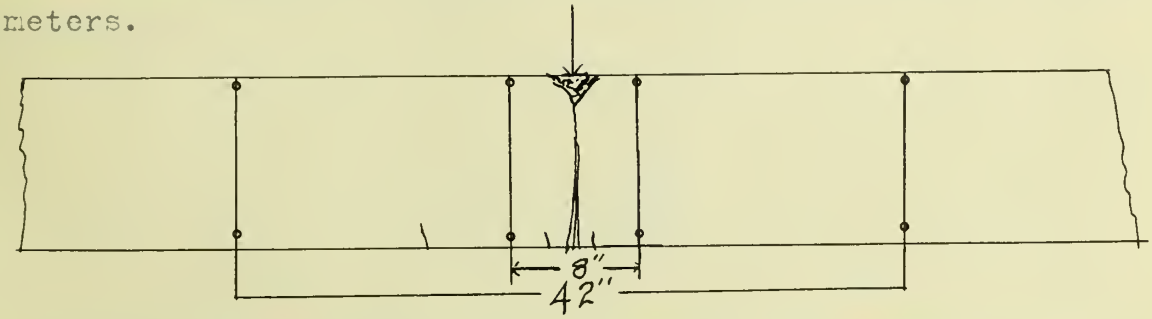
BEAM No. 11. The load was applied at the one-third points. First cracks appeared at load of 9000 lb., one being in the middle and the other near the load point extending 3-1/2 in. from bottom. Behavior of beam was quite similar to Beam No. 5. The crack near the load point ran in a vertical direction, gradually opening and extending higher as the load was increased. The maximum load was reached at 11,000 lb. The load ran down to 10,000 while the readings were being taken and could not again be raised above 10,000 lb. The first sign of crushing was noticed after the load had run down to 9600 lb. the beam having a deflection of .88 in. at this time. The machine was run till load ran down to 5800 lb. at which time the beam was deflecting so rapidly that deflections could not be taken.

The crack was outside of extensometer points on side of No. 1 and 4 and inside points on side of No. 2 and 3.



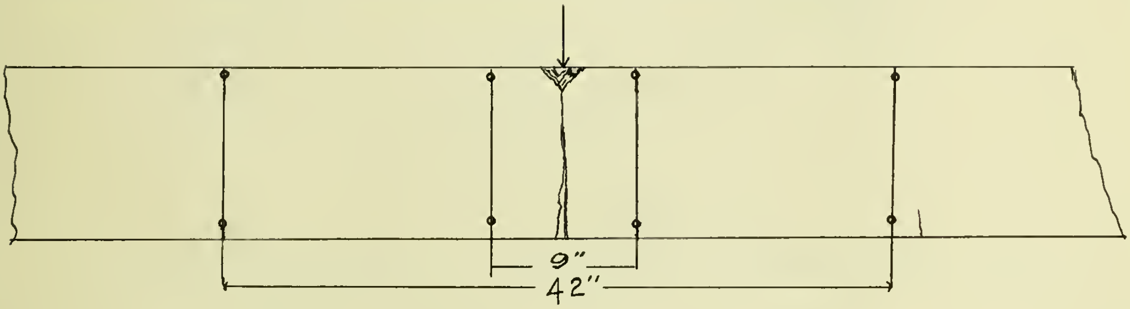
(Above sketch shows manner of failure of beam.)

BEAM No. 21. The load was applied at the center of the span. At the load of 5000 lb. two small cracks became visible near the center of the span, extending 3 in. from the bottom of the beam. At 6000 lb. another crack developed about 2 in. from center of span on the east side of the beam which became visible on the west side when the load reached 7000 lb. at 8800 lb. the load held steady for about one minute while the machine was running. A reading was taken at this point, thinking that the maximum load had been reached. The load gradually ran up till 9800 lb. was reached, at which point the crack at the center extended to within 4 in. of the top and the load dropped to 8200 lb. The load held steady at this load for about ten minutes when crushing of top of the beam at the center took place. The extensometers having the span of 8 in. gave veryunsatisfactory results, especially the two upper extensometers.



(Above sketch shows manner of failure of beam.)

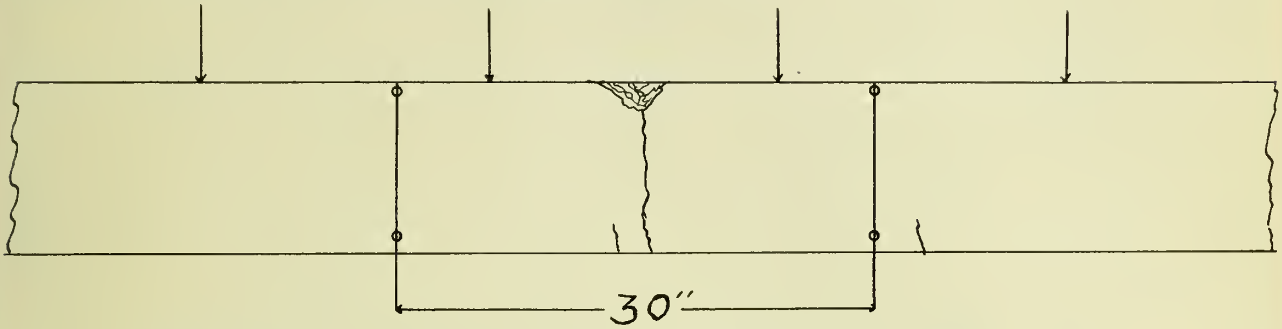
BEAM No. 30. The load was applied at the center of the span. The first crack developed at the load 5000 lb. This crack showed on both sides of the beam and was located at the center of the beam, extending vertically to a height of 4 in. at 6000 lb. a crack 24 in. south of the center and 3 in. high developed. These two cracks were all that developed and the one at the center began to open as the load ran up. The maximum load was reached at 8000 lb. at which point the crack at the center extended to within 3 in. of the top. As soon as the maximum was reached the load ran down to 7500 lb. and held steady for about fifteen minutes when crushing took place under the load. After this the load ran down rapidly.



(Above sketch shows manner of failure of beam.)

BEAM No. 47. The load was applied at eight points. First crack appeared about 18 in. south of the center extending 3 in. high, when 8000 lb. load was reached. Another appeared at the center on the west side of the beam, extending 5 in. high at a load of 9000 lb. At 10,000 lb. the crack at the center became visible on the east side, also a crack showed about 2 in. north of the center on the west side extending 3 in. high. The beam reached the maximum load at 13,000 lb. when the load dropped to 12,000 lb. and the crack at center extended to within 2 in. of top of beam. The first sign of

crushing took place while there was a load of 12,000 lb. on the beam. The load then ran down to 11,400 lb. and the machine was stopped. The beam had deflected so much at this time that the supports had rocked back until they were resting on a flat surface, hence part of the load was taken up by a horizontal thrust tending to overturn the supports.



(Above sketch shows manner of failure of beam.)

V. DISCUSSION.

The curves for all the beams used in this test present the same general characteristics as have been brought out by former tests on reinforced concrete beams. The beams all failed by tension in steel reinforcement. The steel in each case was stressed beyond the elastic limit. The reason for this may be due to the fact that all the beams in these tests were so located in the stacks that they were not likely to become injured by the tumble.

The extensometers used for the 8- and 9-in. span, for Beams No. 21 and 30 did not give satisfactory results. The curves, as shown in Plate IV., page 16 were plotted from the lower extensometer readings and the neutral axis position, assuming

that the neutral axis was the same distance below the top of the beam for a span of 8 in. as for a span of 42 in. through the center. These curves show that the unit deformations for both the upper fiber and the steel are the same for the two extensometer spans during the third stage. The deformation curves in Plates V. and VI., show that the unit deformations in the upper fiber are the same for a span of 9 in. as for a span of 42 in. at the center, while the unit deformations in the steel for the 9 in. span greatly exceed those for the 42 in. span. The curves in Plates VII. and VIII. show that the unit deformations in both the upper fiber and the steel decrease toward the end of the beam. These plates show that the neutral axis, was uniformly the same throughout the entire length of the beam.

The calculated stress in the steel, produced by the uniform load at its maximum is slightly below the elastic limit of the metal. The calculated stress in the steel, produced by the concentrated loads and the loads at the one-third points, at the maximum load, is, in each case above the elastic limit.

The maximum bending moment developed at the center of the span was least in the beam with the uniform load, slightly higher for beams with loads at the one-third points and still higher for beams with concentrated loads.

DATA AND CALCULATED RESULTS FOR BEAMS

Beam No.	Kind of Loading	Maximum Load	Load Considered	K d In.	Bending Moment	Unit Stress In Steel in Lb. Formula	Unit Stress In Steel in Lb. Deformation
5	1/3-Points	11000	11000	4.9	264000	40900	40200
11	1/3-Points	11000	11000	5.5	264000	41900	46400
21	Concentrated	9800	9500	4.3	342000	51700	42200
30	Concentrated	8000	8000	3.6	288000	43500	43300
47	Uniform	13000	13000	4.7	234000	35900	36800

All reinforcing rods of 1/2 in. round, low steel.

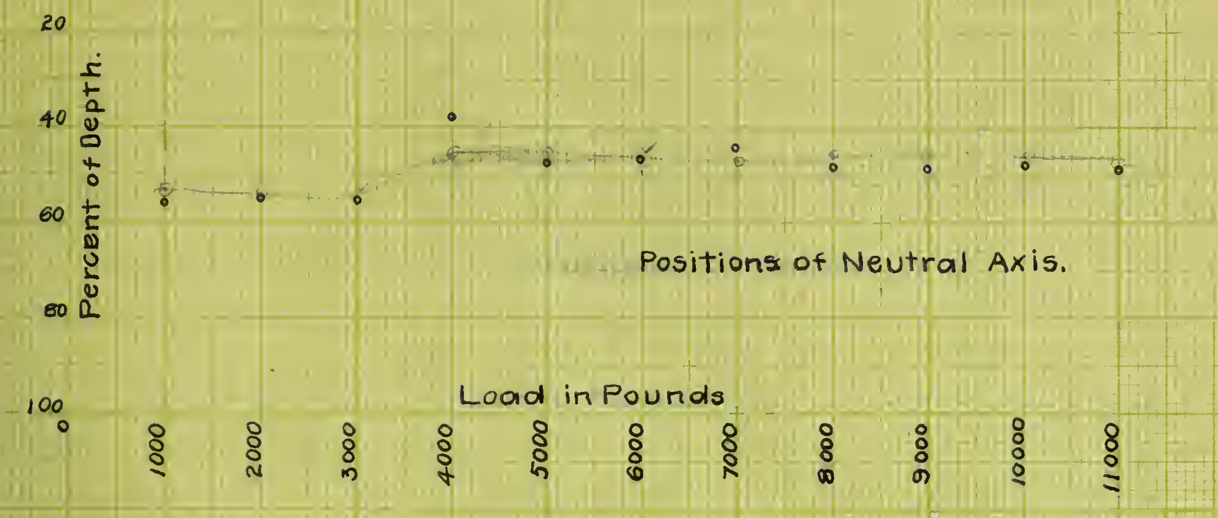
Area of metal is .7854 sq. in.

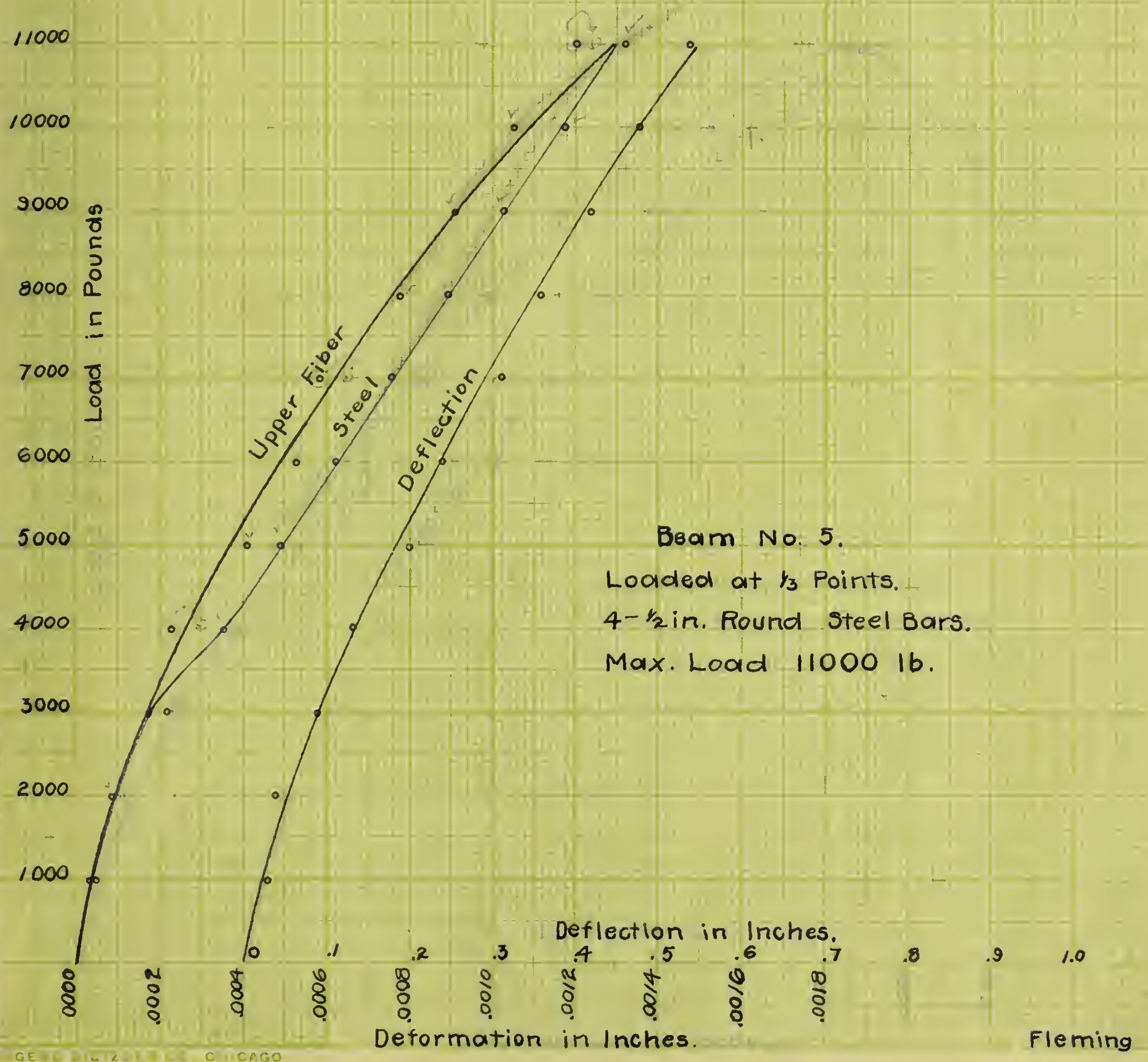
The term Kd, where K is ratio of depth of neutral axis from top of beam, to effective depth, is equal to 10 x (percent depth of neutral axis) since effective depth of beam is 10 in. Moment arm = d(1—.36K).

EXPLANATION OF PLATES AND TABLES

Curves were plotted with applied loads as ordinates and unit deformations and deflections as abscissae. Curves designated,"Upper Fiber" refer to upper fiber of concrete; those designated,"Steel" give deformations under the usual assumption that the deformation in the steel is the same as in the adjacent concrete. The deformations were determined graphically by finding total deformations from the extensometer readings and dividing by the extensometer span. The various positions of the neutral axis are plotted in percents of the effective depth of the beam below the top. The neutral axis was located graphically under the assumption that a plane section before bending remains a plane section after bending.

In tables I to VIII, pages 21 to 28 of original readings, loads are given in pounds exclusive of weight of beam and apparatus. Extensometers No. 1 and 4 were always on the East side of the beams and 2 and 4 on the West side. Extensometers No.1 and 3 were upper and No. 2 and 4 lower. Extensometer readings were in inches. Deflections were measured in inches at the middle of the beam.

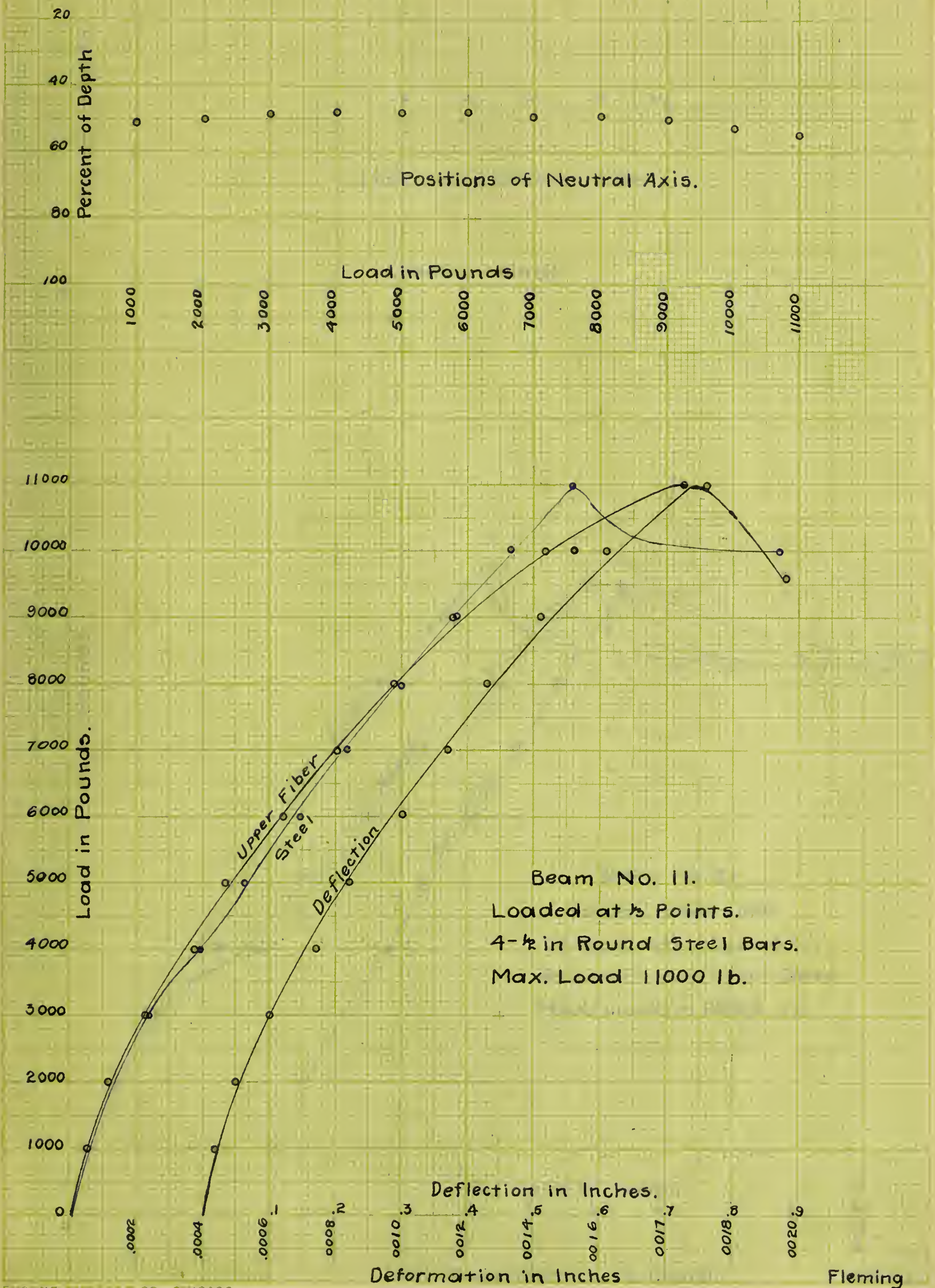

Positions of Neutral Axis.


Beam No. 5.
Loaded at ⅓ Points.
4-½ in. Round Steel Bars.
Max. Load 11000 lb.

Fleming

E. GEO. DIETZGEN CO. CHICAGO

PLATE II



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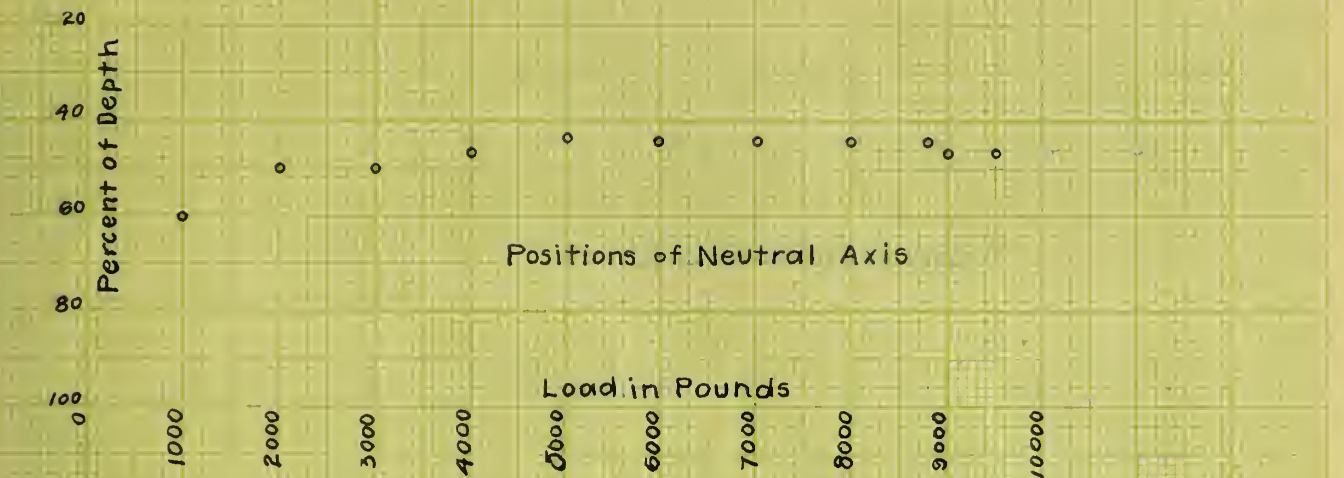
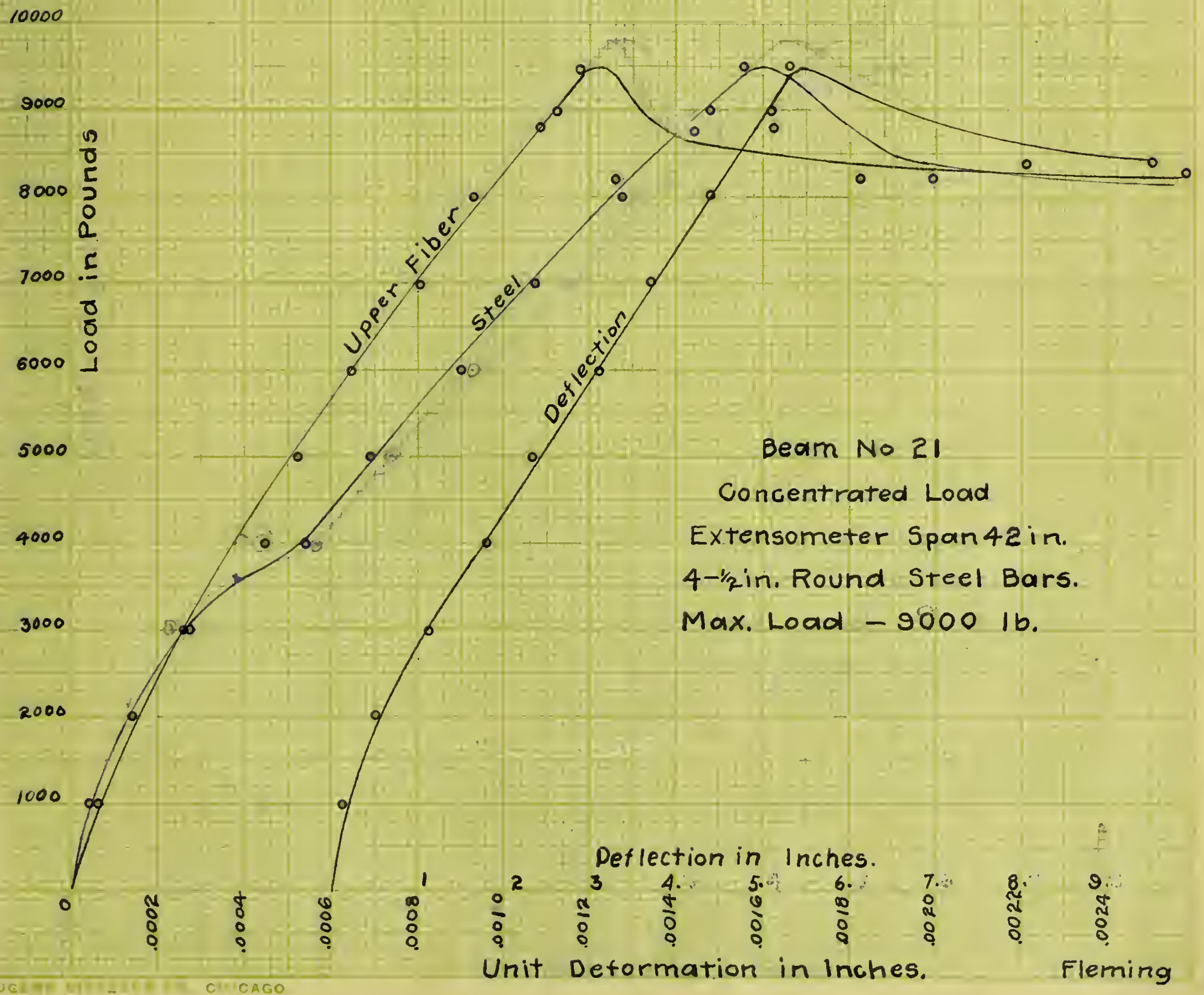
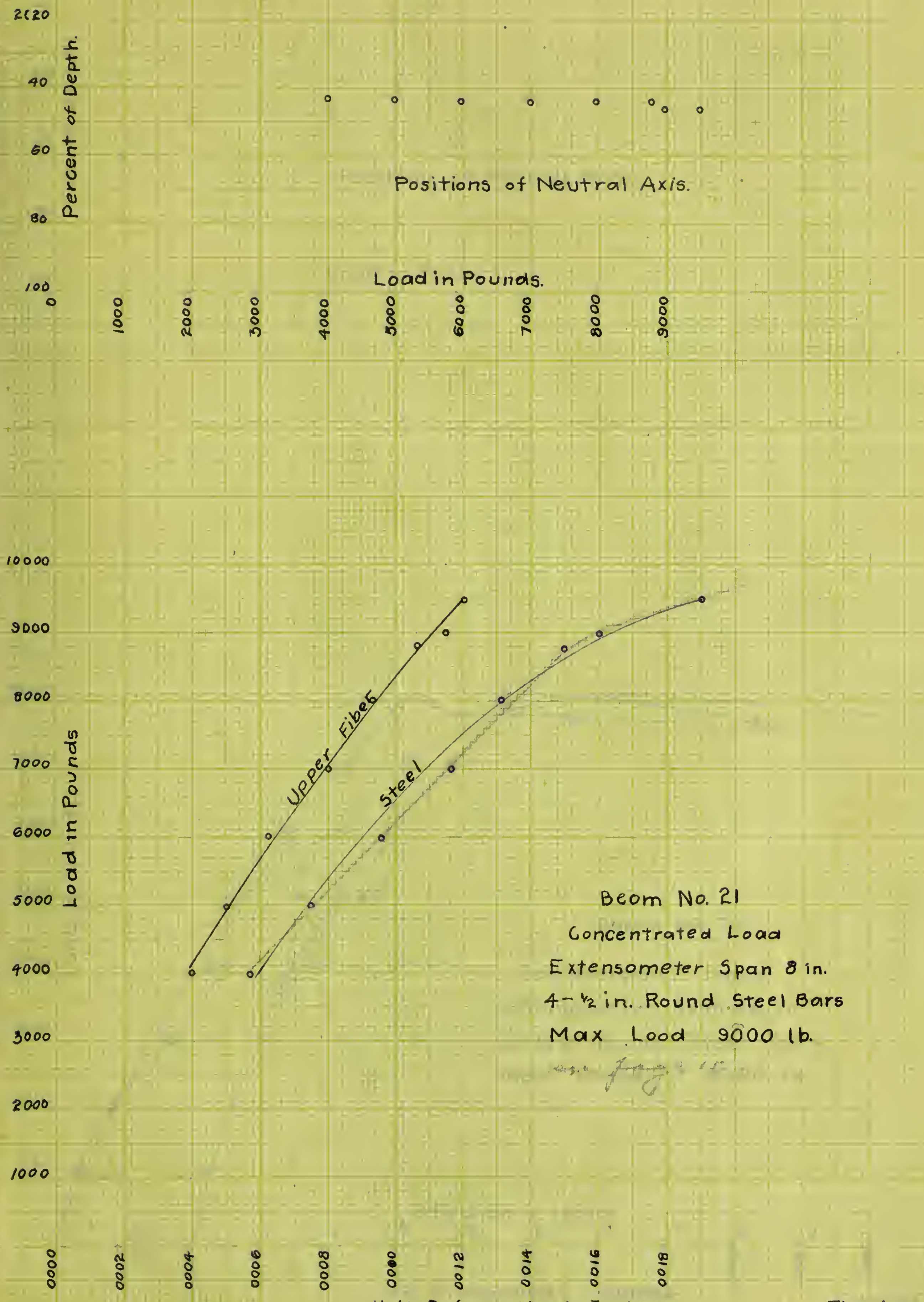




Fleming

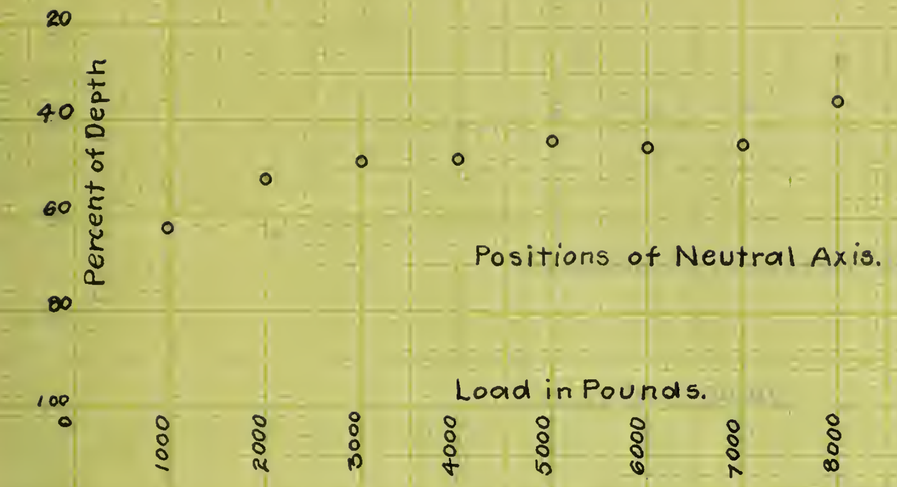
EUGENE DIETZGEN CO. CHICAGO

PLATE IV

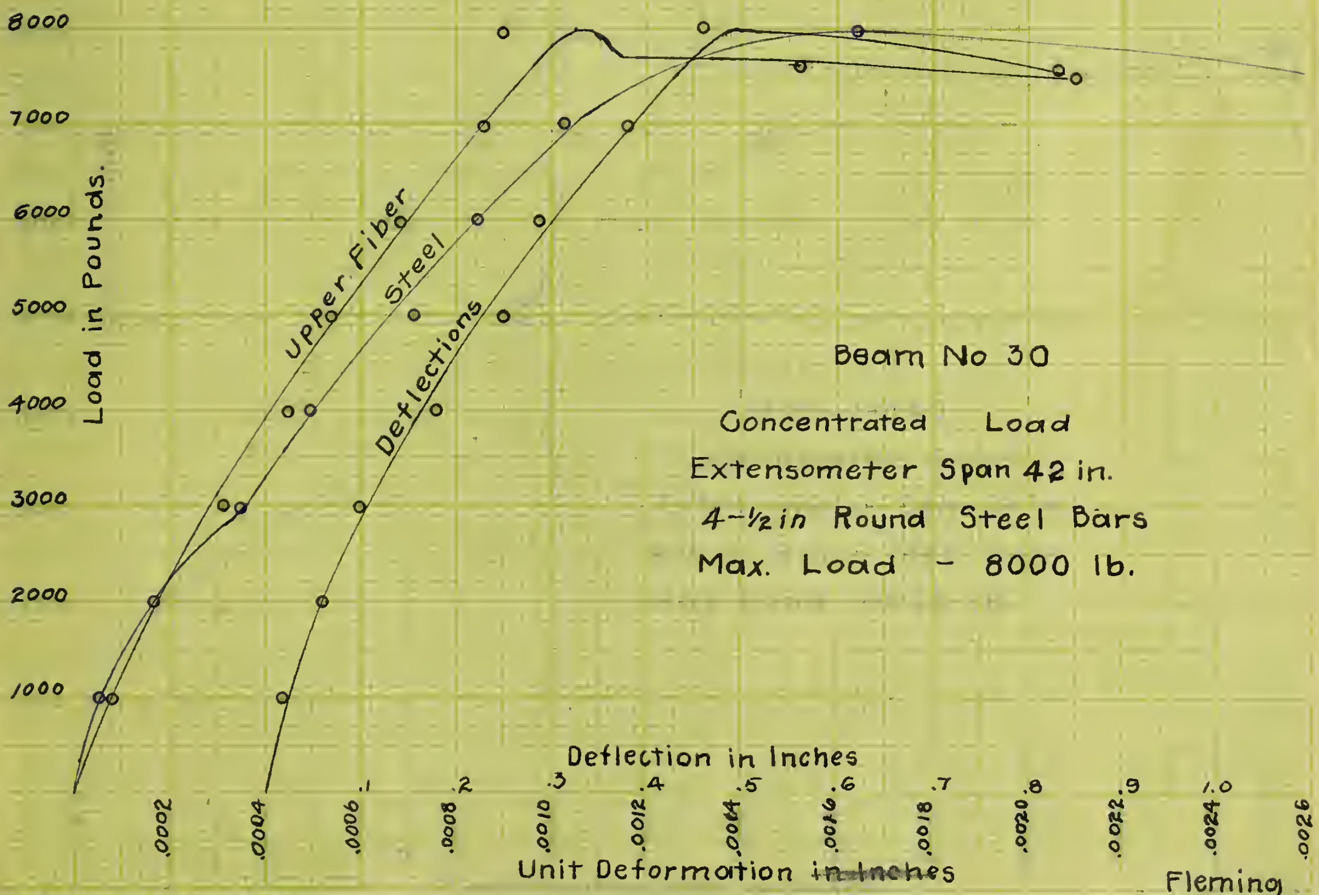


Beam No. 21
Concentrated Load
Extensometer Span 8 in.
4 - ½ in. Round Steel Bars
Max Lood 9000 lb.

Fleming



Positions of Neutral Axis.



Beam No 30

Concentrated Load

Extensometer Span 42 in.

4-½ in Round Steel Bars

Max. Load - 8000 lb.

Fleming

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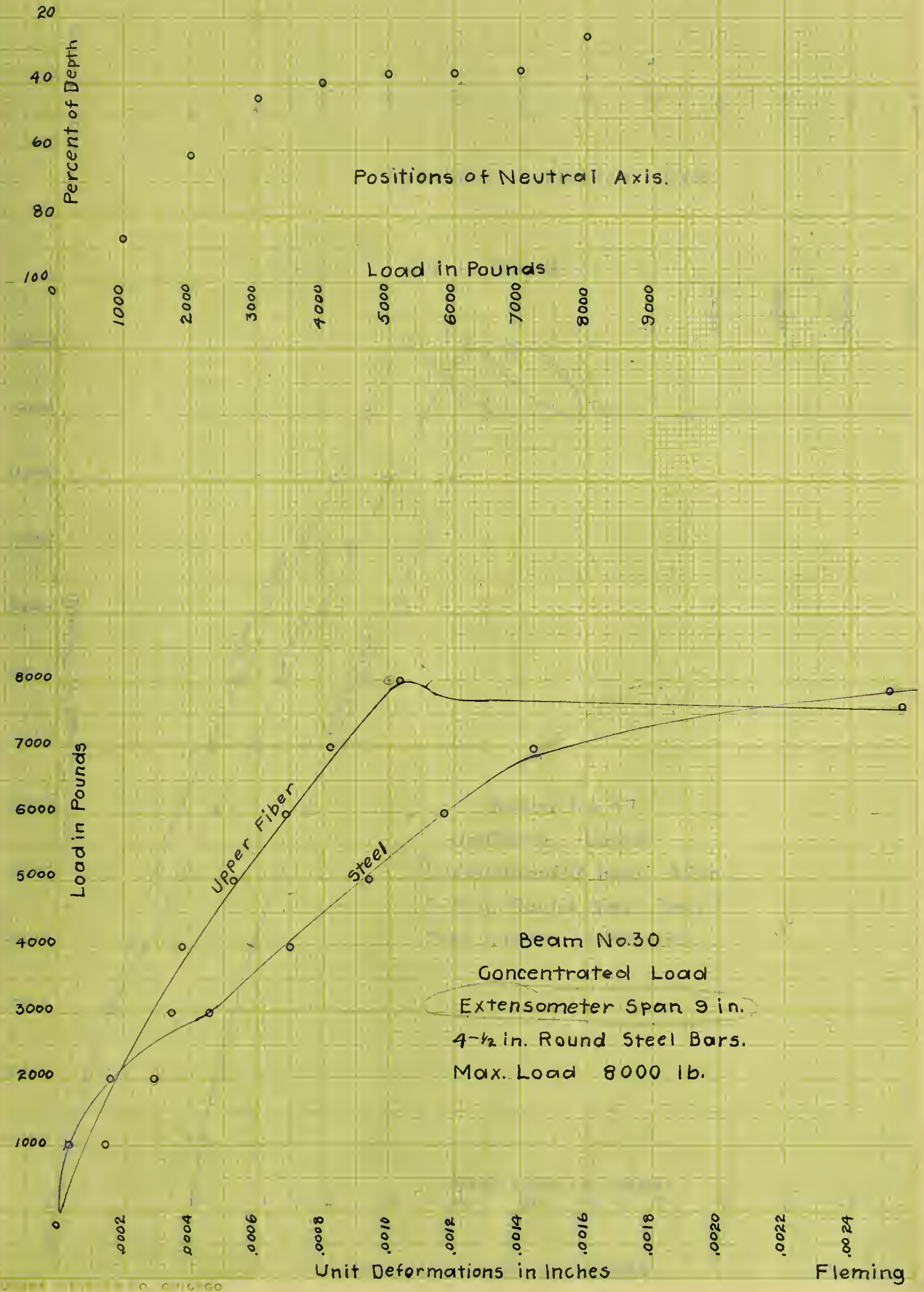
PLATE VI



Beam No.30
Concentrated Load
Extensometer Span 9 in.
4-½ in. Round Steel Bars.
Max. Load 8000 lb.

Fleming

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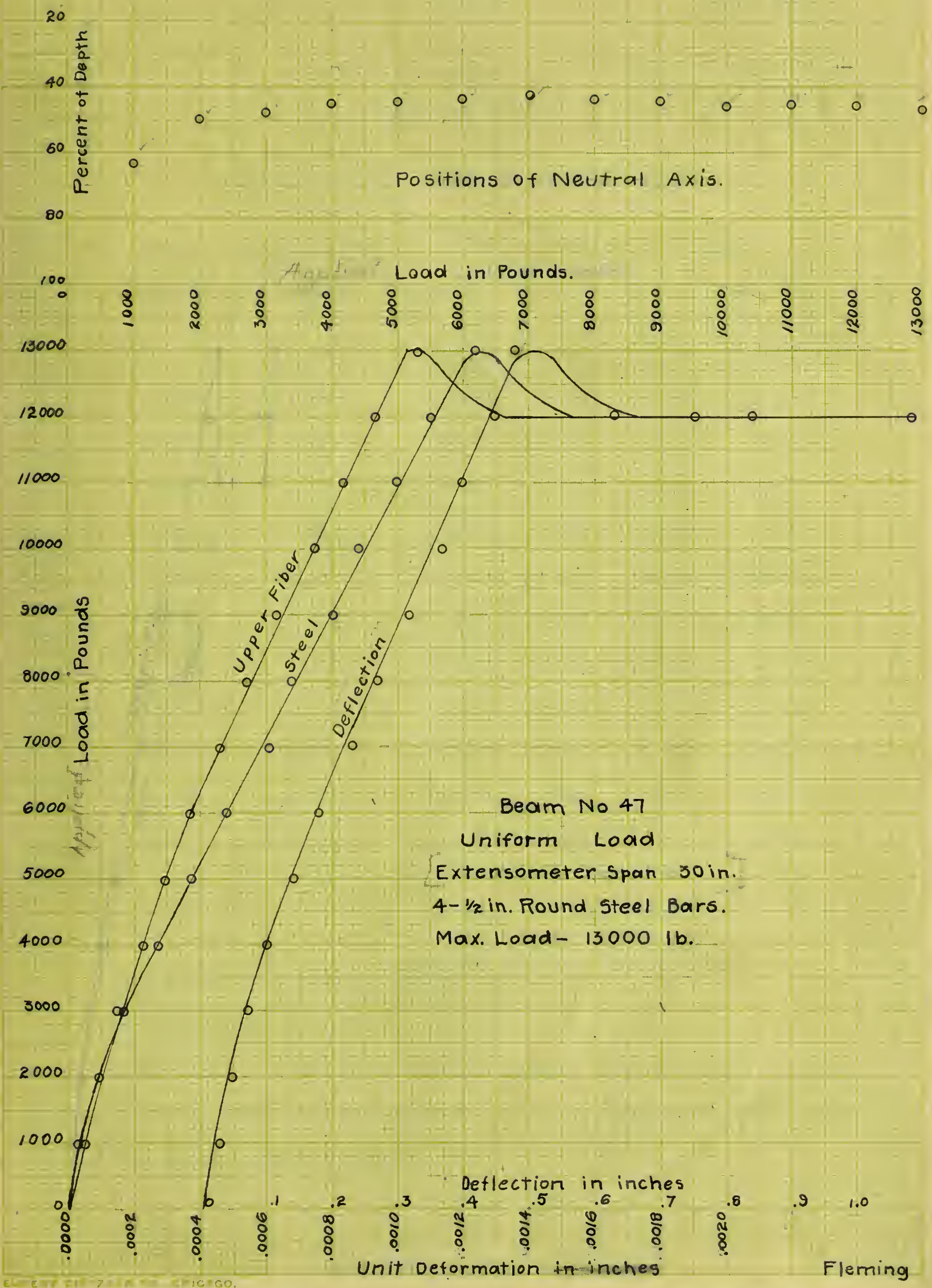
PLATE VII



Beam No 47

Uniform Load

Extensometer Span 30 in.

4-½ in. Round Steel Bars.

Max. Load- 13000 lb.

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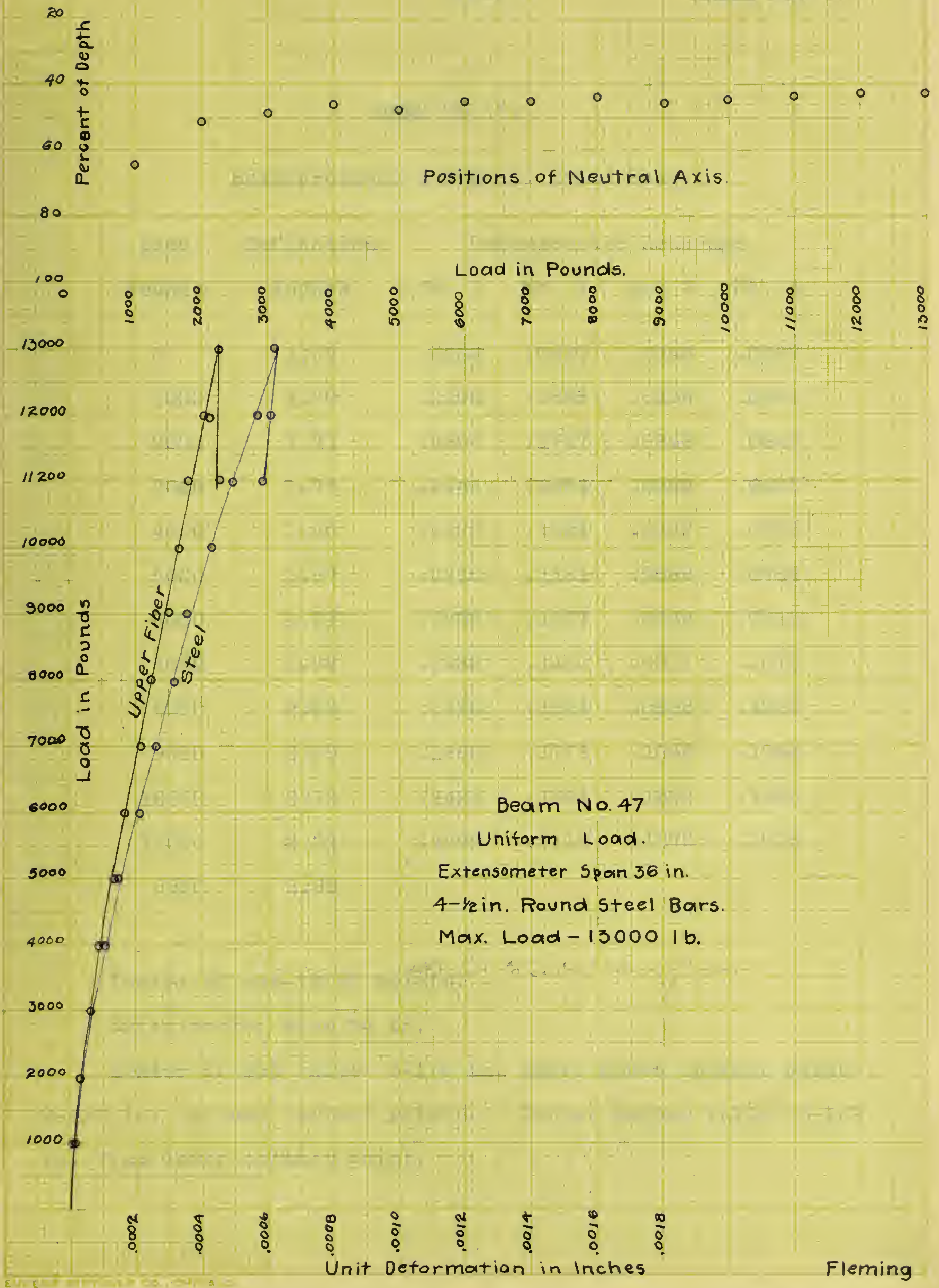
PLATE VIII



Beam No. 47
Uniform Load.
Extensometer Span 36 in.
4-½ in. Round Steel Bars.
Max. Load – 13000 lb.

Fleming

BEAM NO. 5.

Reinforcement 4 1/2 in. Round Rods.

Load	Deflection	Extensometer Readings			
Pounds	Inches	No. 1	No. 2	No. 3	No. 4
0	1.67	.0232	.0630	.0143	.0237
1000	1.70	.0290	.0635	.0194	.0291
2000	1.71	.0354	.0747	.0248	.0343
3000	1.76	.0445	.0854	.0282	.0445
4000	1.80	.0476	.1021	.0447	.0606
5000	1.87	.0710	.1181	.0566	.0764
6000	1.91	.0839	.1327	.0684	.0915
7000	1.98	.0982	.1480	.0811	.1070
8000	2.03	.1120	.1624	.0936	.1220
9000	2.09	.1260	.1772	.1068	.1363
10000	2.15	.1425	.1941	.1222	.1535
11000	2.21	.1592	.2118	.1376	.1708
8800	2.38				

Loaded at one-third points.

Extensometer span 54 in.

Center of top roller 5-1/4 in. above upper contact points. 9-1/2 in. between contact points. Center bottom roller 5-1/2 in. from lower contact point.

TABLE NO. II .

BEAM NO. 11.

Reinforcement, 4 1/2 In. Round Rods.

Load Pounds	Deflection Readings Inches	Extensometer Readings 1	2	3	4
0	1.20	.0192	.0063	.0086	.0180
1000	22	237	72	129	225
2000	25	293	80	181	283
3000	30	284	159	275	394
4000	37	514	303	385	530
5000	42	625	446	498	668
6000	50	744	579	604	793
7000	57	879	720	727	925
8000	63	1034	872	871	1068
9000	71	1090	1022	1018	1212
10000	81	1390	1213	1225	1405
11000	96	1680	1501	1508	1630
9600	2.08	1853	1626	1688	1682
9500	20	----	----	----	---

Loaded at one-third points

Extensometer Span 42 In.

TABLE NO.III.

BEAM NO. 21.

Reinforcement 4 1/2 In. Bars.

Load Pounds	Deflection Readings Inches	Extensometer Readings. 1	3	2	4
0	2.19	.0165	.0515	.0267	.0204
1000	20	217	564	318	245
2000	24	295	640	412	343
3000	30	404	798	559	486
4000	37	513	856	709	640
5000	42	634	969	863	804
6000	50	754	1083	1009	956
7000	56	889	1200	1119	1132
8000	63	1015	1333	1320	1286
8800	70	1132	1449	1452	1435
9000	70	1164	1482	1486	1473
9500	72	1225	1547	1558	1550
9800	--	----	----	----	----
8200	80	1355	1672	1868	1855
8400	3.00	1660	1974	2547	2540

Concentrated Load.

Extensometer Span 42 In.

BEAM NO. 21.

Reinforcement 4 1/2 In. Bars.

Load	Extensometer Readings			
Pounds	1	3	2	4
0	.4872	.3399	.0586	.3787
1000	61	3413	72	95
2000	35	70	50	3818
3000	03	79	13	52
4000	4786	3434	479	89
5000	70	77	443	3921
6000	4770 * 4630	3720	410	59
7000	90	69	374	4003
8000	90	3817	338	50
8800	82	58	304	80
9000	82	65	294	92
9500	63	83	278	113
9800	----	----	----	----
8200	4641	4088	4974	4544
8400	4420	4520	4260	.0293

Concentrated Load.

Extensometer Span 8 In.

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* New zero reading for No. 1.

BEAM NO. 30.

Reinforcement 4 1/2 In. Bars.

Load	Deflection Readings	Extensometer Readings.			
Pounds	Inches	1	3	2	4
0	2.82	.0105	.0040	.0008	.0121
1000	84	167	108	68	169
2000	88	259	184	178	266
3000	92	375	294	328	410
4000	3.00	485	404	425	552
5000	07	600	505	682	694
6000	11	721	619	726	842
7000	20	852	744	933	1002
8000	28	1068	937	1222	1482
7600	65	1775	1600	2665	2680
7500	90	2272	2025	3614	2981

Concentrated Load.

Extensometer Span 42 In.

TABLE NO. VI.

BEAM NO 30.

Reinforcement 4 1/2 In. Bars.

Load	Extensometer Readings			
Pounds	1	3	2	4
0	.1470	.1073	.2729	.0213
1000	80	45	46	200
2000	85	11	78	169
3000	1502	0979	2819	119
4000	39	40	61	69
5000	83	05	2904	23
6000	23	864	48	4979
7000	52	20	90	21
8000	1825	668	3256	4669
7600	2770	4739	4639	3265
7500	3319	3976	0660	3235

Concentrated Load.

Extensometer Span 9 In.

TABLE NO. VII.

BEAM NO. 47.

Reinforcement 4 1/2 In. Rods.

Load Pounds	Deflection Readings Inches	Extensometer Readings			
		1	3	2	4
0	2.03	.0039	.0000	.0000	.0009
1000	06	78	25	18	28
2000	08	103	59	47	56
3000	10	150	105	86	98
4000	13	205	163	134	151
5000	17	262	217	185	206
6000	21	318	282	234	258
7000	26	379	345	290	311
8000	30	438	405	339	364
9000	35	509	471	398	422
10000	40	578	533	433	479
11000	43	642	597	492	533
12000	48	714	633	547	598
13000	51	782	733	620	643
12000	87	1698	1650	1880	1984
12000	3.03	2030	2000	2330	2410

Uniform Load.

Extensometer Span 30 in.

TABLE NO. VIII.

BEAM NO. 47.

Reinforcement 4 1/2 In. Rods.

Load Pounds	Deflection Readings Inches	Extensometer Readings 1	 3	 2	 4
0		.0000	.0133	.0091	.0080
1000		.4989	147	84	91
2000		65	167	60	110
3000		35	197	34	139
4000		10	231	5	170
5000		.4865	270	.4968	209
6000		24	309	26	249
7000		4785	357	4879	294
8000		45	403	32	340
9000		4696	452	4790	390
10000		51	502	41	434
11000		10	549	4695	482
12000		4575	596	42	531
13000		20	643	4594	575
12000		45	628	4609	560
12000		35	630	4609	561

Uniform Load.

Extensometer Span 36 in.

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